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THE EFFECTS OF BUOY DENSITY AND BUOY FLASHING PATTERN ON STEERING THROUGH A CHANNEL BEND

U.S.DEPARTMENT OF TRANSPORTATION

MARITIME ADMINISTRATION
OFFICE OF RESEARCH AND DEVELOPMENT

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Varying densities of buoys placed on the outside edge of a 35 degree turn were assessed in terms of their effect on steering a VLCC through the channel bend. Low, medium, and high densities of buoys representing 1¼ nm spacing, ½ nm spacing and 1/8 nm spacing respectively were investigated and compared to a condition in which a Rate of Turn Indicator (ROTI) was employed. In general, the results demonstrated that too little information was provided by the 1¼ nm spacing condition when compared to the ½ nm spacing condition. It was also found that too much information as defined by the 1/8 nm spacing condition created a rigid perceptual barrier which the pilots attempted to avoid by keeping further to the right of the channel at the turn point. Optimal performance in steering the turn was induced by the medium density buoyed turn (i.e., ½ nm) with the ROTI condition running a close second. The effect of simple perceptual principles in affording motion and position information for steering channel bends is discussed.

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CHAPTER 1

INTRODUCTION

Varying densities of buoys placed on the outside edge of a 35 degree turn were assessed in terms of their effect on steering a VLCC through the channel bend. Low, medium, and high densities of buoys representing 1¼ nm spacing, ½ nm spacing, and 1/8 nm spacing respectively were investigated and compared to a condition in which a Rate of Turn Indicator (ROTI) was employed. In general, the results demonstrated that too little information was provided by the 1¼ nm spacing condition when compared to the ½ nm spacing condition. It was also found that too much information as defined by the 1/8 nm spacing condition created a rigid perceptual barrier which the pilots attempted to avoid by keeping further to the right of the channel at the turn point. Optimal performance in steering the turn was induced by the medium density buoyed turn (i.e., ½ nm) with the ROTI condition second best. Subsequent experimentation indicated that when medium density buoys are used as steering aids during nighttime conditions, the flashing patterns of these buoys do not add substantially to performance. However, the patterned flashing condition did afford more consistency in trackkeeping relative to the sequential flashing condition. The effect of simple perceptual principles in affording motion and position information for steering channel bends is discussed.

Steering implies that the human must discriminate between openings in the environment and physical obstacles or barriers. In the open sea, the obstacles or barriers which must be distinguished are provided by course and position information which is deviant from intended course or position. Since there are no obstacles on the waters of the ocean, excepting for other ships, this distinction between openings and barriers is not a refined perceptual process but a judgmental process employing course and position criteria as specified by the intentions of the master. Minor deviations in course and position may be tolerated since physical barriers are essentially nonexistent. Automated steering, therefore, is an immensely functional method of freeing up manpower from the tedious chore of maintaining a vigilance on the gyro compass. Furthermore, with the advances in technology the steering function can be automated with safety and accuracy in the open sea. This, however, is not quite the case when steering in restricted waters.

Steering in restricted waters requires that the human operator constantly make the distinction between obstacles and/or barriers and openings which the man-ship system can maneuver through. This operation is further complicated by perturbations which act upon the vessel such as, wind, current, shallow water effects and bank suction and cushion effects which alter ship position and course in confined waterways. Such perturbations are exceptionally difficult to predict and to perceive. Consequently, steering under these circumstances becomes a more difficult problem because the margin of error has been reduced and safety and accuracy requirements are more stringent than is the case in the open sea. Steering in confined waters, therefore, requires that the human operator be cognizant of wind, current, and shallow water effects and be capable of anticipating these effects such that compensation can be made in order to preserve an opening for the vessel in which to maneuver. However, given skilled pilots with local knowledge of wind, current, bank, and shallow water effects, steering vessels in straight channels can be accomplished safely and accurately once the pilot establishes a state of balance between ownship forces and the environmental forces acting upon the vessel. Nevertheless, serious problems do exist when steering large vessels around channel bends.

In straight legs of a channel once a balance has been achieved by the pilot in order to compensate for forces acting upon the vessel, the ship can essentially stay in the groove, so to speak, and maintain a relatively consistent trajectory. However, when approaching a channel bend, this balance between ship hydrodynamic characteristics and the physical forces acting upon the vessel is disrupted requiring both a change in course as well as speed and position. New perceptual information is now required by the pilot in order to take the necessary maneuvering action to maintain a safe position in the channel while negotiating the turn. This process becomes one of determining what information must be picked up by the pilot in order to

meet this end. The problem now becomes difficult due to the relatively slow response of large vessels to rudder and engine commands and the slow changes in motion which result from these lags between command and perceptible response of the vessel. This is further compounded by the fact that large vessels in restricted channels cannot move fast due to the danger of squat, reducing the under keel clearance of the vessel. Consequently, a large vessel being steered by a pilot through a channel bend provides a serious perceptual problem in terms of picking up the needed information enabling the pilot to take action in order to maintain an opening for the vessel and to avoid channel boundary barriers and obstacles.

It has been found by Williams and Gilder (1979 in press) that the perception of initial yaw of a vessel of 250,000 DWT can take on the average 16 seconds and that the perception of change of rate of yaw requires an additional 15 seconds in order to be perceived by the pilot. Such lags in detection of motion imply the need for providing meaningful yaw information quickly.

Determining the information which must be picked up in order to execute a channel bend with 280,000 DWT tanker was the objective of a series of experiments conducted at CAORF. Our question was not how the information was picked up but what information exists and what information could be added to the visual environment in order to improve ship trackkeeping given the slow changes in motion produced when steering a large vessel around a channel bend. Ideally, then, the problem of steering through a channel bend becomes one of providing enough reference points such that the flow of turn information would be improved and consequently the relative threshold of perceiving slow motion could be reduced. It has been found by Graham (1965) in a review of early experiments that motion thresholds can be reduced ten times by increasing the number of clearly visible reference points. This is why night driving is more dangerous than daylight driving. The flow of information is reduced. What is meant by the flow of information is that enough points in visual space are provided such that a gradient of velocity vectors can be perceived. That is, a gradient of the ratio of speed of motion of a point and the perceived distance travelled by the point in space and time can be established. For example, Figure 1 exhibits a channel of specified dimensions and spacing of buoys. Figure 2 is a perspective view of the same channel; the vector lengths, however, indicate the perceived speed and distance which the buoys travel in space and time as the turning motion is initiated. That is, those buoys which are nearest to the observer appear to move to the left opposite the direction of vessel motion more rapidly than those farther ahead. Each successive buoy ahead appears to move more slowly to the left. Therefore, the ratio of perceived speed of motion to

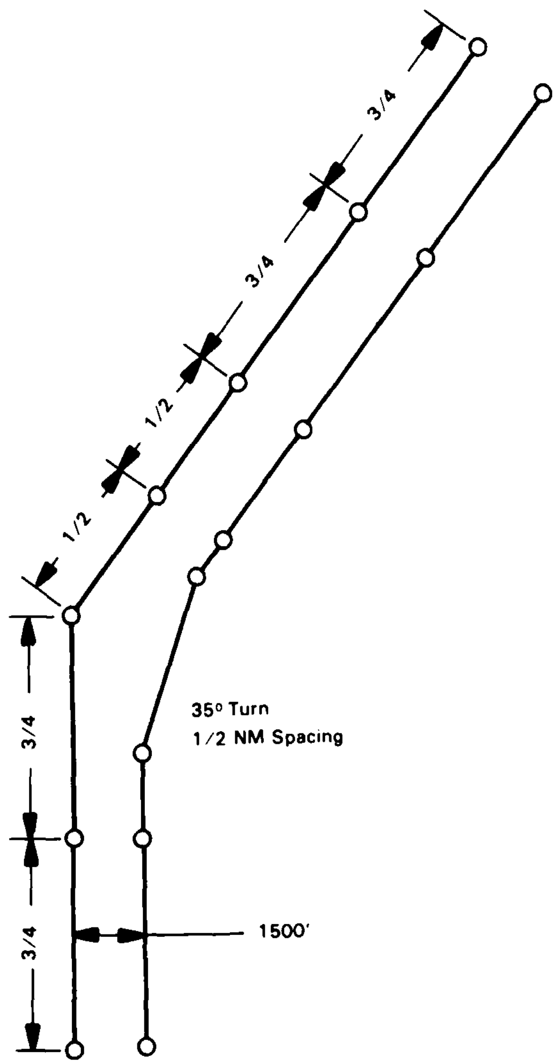


Figure 1. A 35° Turn in a 1500' Channel with ½ NM Spacing at the Outside Edge of the Second Leg

distance travelled by the object varies from the near buoy to the furthest in a graded manner. Figure 3 adapted from Gibson (1950) shows these velocity gradients for points in space and time as seen by a pilot attempting a landing on a runway. As can be seen, those points closest appear to the pilot move the fastest in space and time establishing a gradient of vectors from points in space across the entire visual field. This is what is meant by a flow field or information flow.

Given the empirical evidence to date and the notable problem of perceiving yaw and rate of change of yaw, the present research was designed to determine the configuration of reference point needed to produce the desired flow of information enabling the pilot to accurately negotiate a turn with a 280,000 DWT tanker. In addition, performance of pilots steering a turn was also investigated employing a rate of turn indicator with only a minimal number of buoy points marking the channel bend.

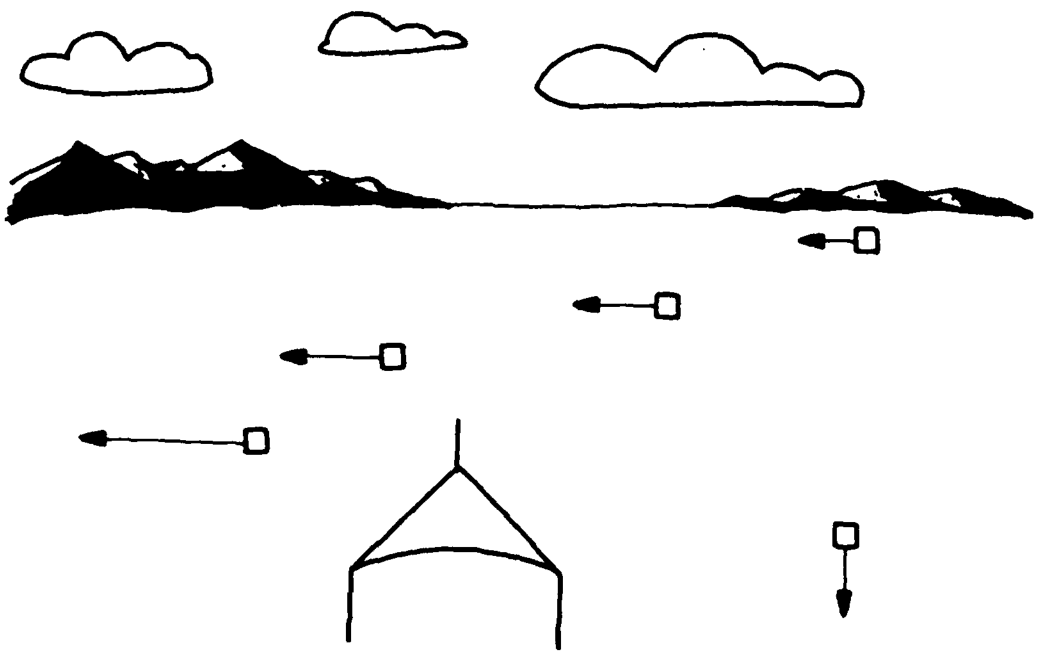
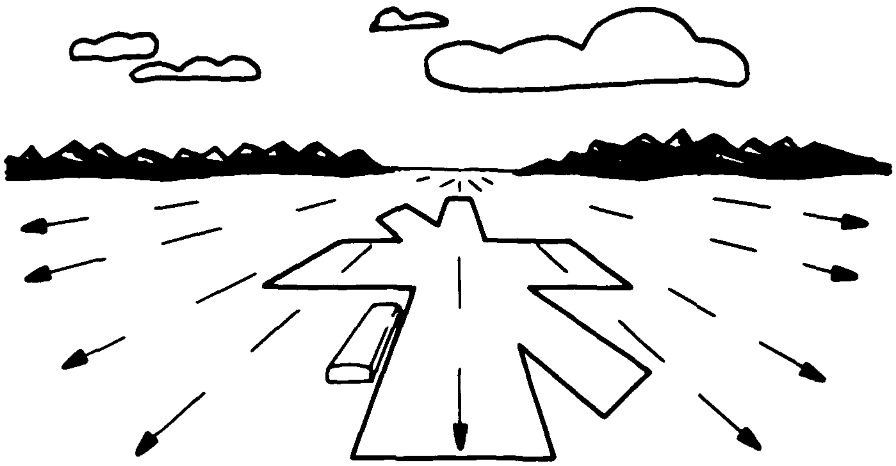


Figure 2. A Velocity Gradient of Buoys Moving in Space and Time as a Ship Executes a Turn



Motion perspective. The optical flow in the visual field as an observer moves forward. The view is that as seen from an airplane on level flight. The direction of apparent movement in the terrain below is signified by the direction of the arrows: speed of apparent movement is indicated by the length of the arrows.
(From Gibson, 1950)

Figure 3. Motion Perspective

CHAPTER 2

EXPERIMENT 1

2.1 METHOD

Subjects: Six pilots with unlimited tonnage endorsements were selected to take part in the experiment. All pilots were members of the Sandy Hook Pilotage Association, New York, New York, USA. None of the pilots had experience maneuvering a vessel of the size (i.e., 280,000 DWT) employed in this experiment but have had experience on a variety of vessels of lesser size.

Scenario Design: The fundamental channel dimensions of this experiment consisted of: Width = 1500 feet, Leg 1 Length = 1½ nm, Leg 2 Length = 1½ nm, Turn Angle = 35 degrees to the right, Buoy Spacing = 1¼ nm, Turn Configuration = turn point (i.e., 1 buoy marking the inside or apex of the turn).

Three different buoy spacing arrangements were superimposed upon this basic channel design. These arrangements consisted of low, medium, and high densities of buoys placed along the outside edge of the second leg of the channel described above (see Figures 4, 5, and 6). The low buoy density condition was identical to the fundamental channel design, Figure 4. The medium buoy density turn was again identical in all respects to the fundamental channel design with the exception that within the first 1½ nm of the outside edge of the second leg buoys were spaced at ½ nm intervals, Figure 5. The high buoy density turn was again identical to the fundamental channel with the exception that within the first nautical mile (1 nm) of the outside edge of the second leg, buoys were spaced at 1/8 nm intervals, Figure 6.

Vessel Characteristics: A 280,000 DWT VLCC was employed as the test vessel. All hydrodynamic equations of motion were derived from test tank data and programmed into the computer for simulation. The vessel dimensions were as follows. Beam = 173.9 feet, LOA = 1,125.4 feet, Draft = 72.4 feet, Height of Eye = 65.0 feet, and Length from Bow to Bridge = 950 feet.

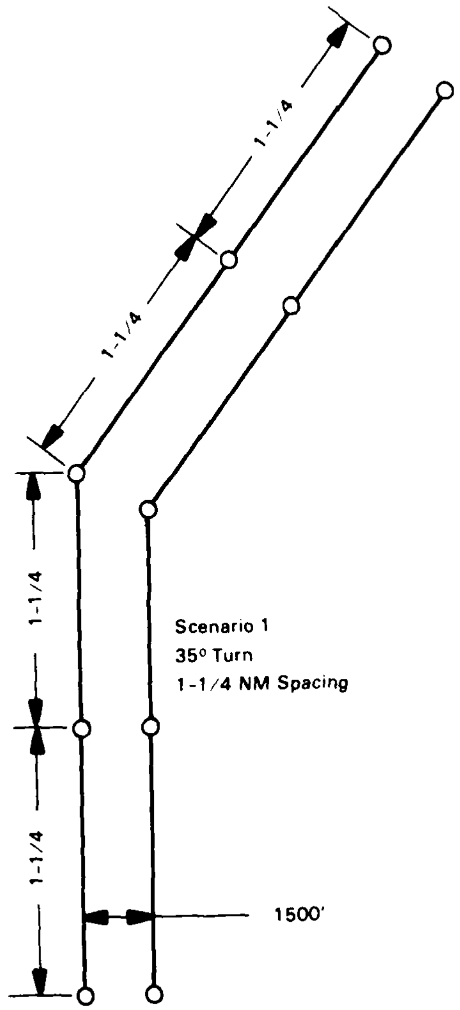


Figure 4. Fundamental Channel Design Also Employed as Low Density Buoyed Turn

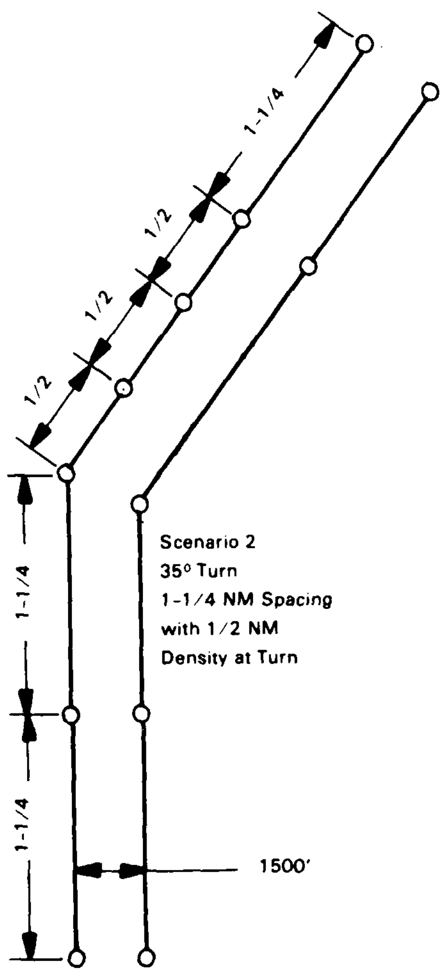


Figure 5. Medium Density Buoyed Turn

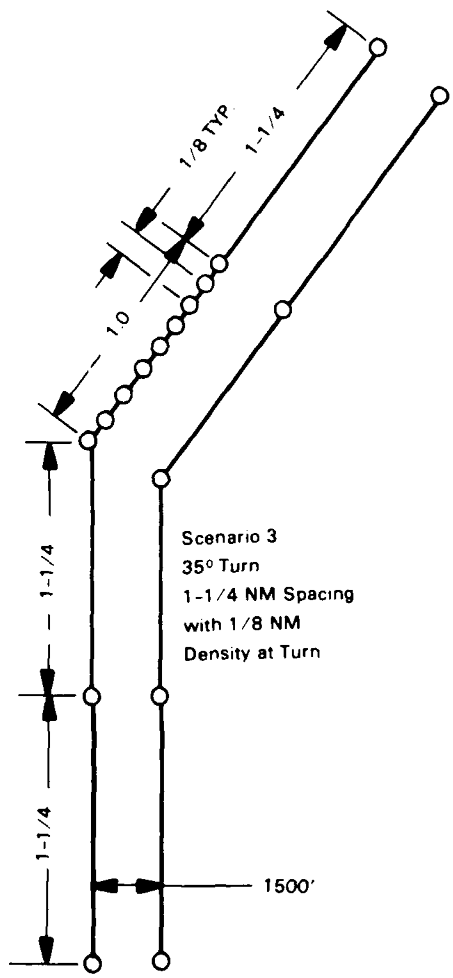


Figure 6. High Density Buoyed Turn

Experimental Design: A within subjects analysis of variance (ANOVA) was employed to structure the experiment (Kirk, 1968). Four separate conditions were employed.

Condition A_1 – Low density buoyed turn with a Rate of Turn Indicator (ROTI) available for use onboard the vessel. Neither gyro compass nor radar was operational.

Condition A_2 – Low density buoyed turn. Neither ROTI nor radar nor gyro compass was operational.

Condition A_3 – Medium density buoyed turn. Neither ROTI nor radar nor gyro compass was operational.

Condition A_4 – High density buoyed turn. Neither ROTI nor radar nor gyro compass was operational.

Table 1 presents a matrix of the experimental conditions by six pilot test subjects. Each test subject was given a different random order of experimental conditions to be run.

Following the collection of all data, non-orthogonal correlated t tests were conducted comparing selected pairs of the four conditions.

Experimental Procedure: Prior to the initiation of the experiment, each pilot test subject was allowed to familiarize himself with the handling of the test vessel by maneuvering through a standard slalom course employed for test subject familiarization at the CAORF simulator. Upon completion of the familiarization run, each subject was required to transit the specified channel under all four experimental conditions. Clear visibility was simulated for all experimental trials. Each subject was instructed to maintain a consistent position on the center line of the channel as was reasonably possible given the absence of radar and gyro compass. A uniform under keel clearance of 10 feet was assumed throughout each run with light and variable wind of 10 kts and variable but negligible current.

TABLE 1. MATRIX OF EXPERIMENTAL CONDITIONS BY TEST SUBJECT

Subject #	A_1	A_2	A_3	A_4
1	3	2	1	4
2	4	3	2	1
3	3	4	1	2
4	4	2	3	1
5	2	1	3	4
6	2	3	1	4

Note: The numbers in each cell represent the order in which the conditions were run.

Performance Measures: Throughout each test run several measures of performance were recorded. These measures include:

1. Frequency of hard over rudder commands in direction of turn inferred to indicate the pilots' capability to negotiate a smooth, consistent turn.

2. Average track deviation reflecting the mean deviation from the center line of the channel while negotiating the turn.

3. Variability of track deviation reflecting the standard deviation in trackkeeping employing the center line as a zero reference.

4. Maximum deviation from track while maneuvering the channel bend.

5. Variability in rate of turn while maneuvering through the channel bend.

6. Swept path of vessel reflecting the area of the channel which the vessel occupies while steering through the turn. The closer swept path to the beam of the vessel, the greater the control over maintaining a steady turn.

An examination of this battery of performance data will indicate the accuracy with which the pilot can maneuver this large vessel through the channel bend and the safety with which the turns were made as a function of the experimental conditions examined.

2.2 RESULTS

The analysis of the data for all performance measures recorded are presented in Table 2 along with those conditions which produced statistically significant differences

TABLE 2. MATRIX OF EXPERIMENTAL CONDITIONS BY PERFORMANCE MEASURES*

	A_1 Low Density With ROTI	A_2 Low Density Without ROTI	A_3 Medium Density Without ROTI	A_4 High Density Without ROTI
Total Frequency of Hard Over Rudder Commands	22	52	26	30
Average Track Deviation	69.79′	71.55′	65.32′	86.52′
Variability of Track Deviation	42.51′	40.82′	29.57′	37.48′
Maximum Track Deviation	142.20′	136.82′	119.33′	137.56′
Variability of Rate of Turn	0.06°	0.07°	0.06°	0.05°
Swept Path	227.42′	240.26′	230.45′	237.30′

*All values in each cell represent the mean level of performance for each index unless otherwise specified.

in man-ship performance while maneuvering through the channel bend. Only those comparisons which were found to be reliable at greater than 90 percent for a one-tailed test will be discussed. All other comparisons are therefore considered nonsignificant, that is, no difference were found which are of a reliable nature.

Total Frequency of Hard Over Rudder Commands: Three comparisons of this index of performance were found to be statistically and meaningfully significant in interpreting the data. These comparisons were:

1. With ROTI vs. Low Density ithout ROTI (22 vs. 52) 't' = 2.66, $p < 0.025$ (reliability = 97.5 percent).

2. Low Density vs. Medium Density (52 vs. 26) 't' = 2.06; $p < 0.05$.

3. Low Density vs. High Density (52 vs. 30) 't' = 1.74; $p < 0.01$.

These analyses indicate that fewer hard over rudder commands were required to control the vessel while operating with ROTI or with medium or high buoy densities marking the first nautical mile of the outside edge of the second leg. This can be interpreted as meaning that the increase in buoy density affords greater control to the pilot in executing the turn requiring less rudder effort on the part of the vessel. The data also indicate the equality of effect which can be achieved either by increasing buoy density at the turn or by employing an electronic rate of turn indicator onboard the vessel.

Average Track Deviation: Only one comparison between any two conditions without ROTI was found to be significant as a result of this index of performance; that comparison was Medium Buoy Density vs. High Buoy Density (65.32′ vs. 86.52′); 't' = 2.30, $p < 0.05$. This analysis again indicates the effectiveness of the medium buoy density turn markings in reducing excursions from the center line of the channel. However, the high buoy density produced the greatest average deviation from the center line reference. Examination of the track plots has indicated that given high buoy density the pilots attempted to stay to the right of the channel as if to avoid a rigid barrier created by too many buoys on the outside edge of the second leg. Although the other comparisons were nonsignificant, the trend of the data indicates that the ROTI condition was also superior to the low density buoy condition and the high density buoy condition.

Root Mean Square Track Deviation: Since this measure is essentially a transform of the average track deviation through the turn, the results of the analysis and the trend of the data were the same as for the average track deviation measure and needs no further discussion.

Maximum Track Deviation: Again only one comparison was found to be worthy of report, however, with a lesser degree of confidence. That comparison of note again was between the Medium Density Buoyed Turn vs. the High Density Buoyed Turn (119.33' vs. 137.56') 't' = 1.66, $p < 0.10$. Here again the ½ nm buoy spacing proved to be superior in providing information to the pilot in order to reduce the maximum excursion from the centerline of the channel while executing the turn. The trend of the data also shows that this medium density configuration is superior to all conditions including the ROTI condition in minimizing excursions from the channel centerline.

Variability of Rate of Turn: Table 2 depicts the variation in rate of turn as the pilot maneuvers through the channel bend. Two comparisons were found to reflect significant differences in terms of consistency with which the pilots maneuvered the turn. These comparisons were ROTI vs. Low Density Buoyed Turn (0.06 vs. 0.07; 't' = 1.87, $p < 0.10$) and Low Density Buoyed Turn vs. High Density Buoyed Turn (0.07 vs 0.05; 't' = 1.79, $p < 0.10$). The data indicated that as the number of reference points in the turn increases, the rate of turn becomes more consistent. As is indicated in Table 2, when going from Low to High Density Buoyed Turns the variability in rate of turn decreases from 0.07 to 0.06 to 0.05. Again with the Rate of Turn Indicator performance is also improved over the Low Density Buoyed Turn and is essentially equivalent to the Medium and High Desnity Buoyed Turn configurations. Although increasing the number of buoys at the outside edge of the second leg improves the consistency in turning the channel bend, the increased number of buoys also creates the perception of a rigid barrier to be avoided as indicated by the Maximum Track Deviation presented above.

Swept Path: Swept path is measured as the distance between the port most and starboard most extremities of the vessel as it makes its way through the channel bend. It reflects the degree of control the pilot has over lateral slippage through the channel bend. Three comparisons were found to be significant for this performance index. As can be seen from Table 2, those significant comparisons are:

1. With ROTI vs. Low Density Buoyed Turn (227.42' vs. 240.26') 't' = 1.43, $p < 0.10$.

2. Low Density Buoyed Turn vs. Medium Density (240.26' vs 230.45') 't' = 1.51, $p < 0.10$.

3. Medium Density Buoyed Turn vs. High Density (230.45' vs. 237.30') 't' = 1.51, $p < 0.10$.

The results of this analysis again point to a relatively consistent trend indicating the superiority of a medium density buoyed turn to that of a high density or low density buoyed turn. The medium density condition when compared to the low density condition indicates too little information is available and when compared to the high density condition indicates too much information is available producing a rigid barrier or obstacle which must be avoided. Consequently, the track plots show that pilots stay to the right of the centerline while negotiating the high density channel bend. Again the data also point to the capability of the pilot to effectively make use of the ROTI in maneuvering the channel bend by minimizing the swept path of the vessel.

One final technical note must be made with respect to the reporting of these findings. It is typically held as a matter of convention to report as statistically significant only those t values with p values less than 0.10. Here, however, some comparisons reported were only less than 90 percent of confidence. This was done since an examination of the data indicates that the differences which were significant were rather small and such differences typically require a larger sample of data to obtain statistical significance at the $p < 0.05$ or 95 percent confidence level. This being the case, it was determined that the variation in performance within each experimental condition was quite small relatively speaking. Consequently, in most cases if one or two additional subjects were run those comparisons reported at $p < 0.10$ or 90 percent confidence level could have easily become significant at the $p < 0.01$ or 99 percent confidence level. As a result of these considerations the significance convention was relaxed several percentage points. If, on the other hand, larger differences between comparisons were found with the same consistency of performance within experimental conditions the six subjects sample points obtained would have been adequate to push those 90 percent confidence levels well within the 95 percent confidence level convention. However, due to such small differences such was not the case as discussed above.

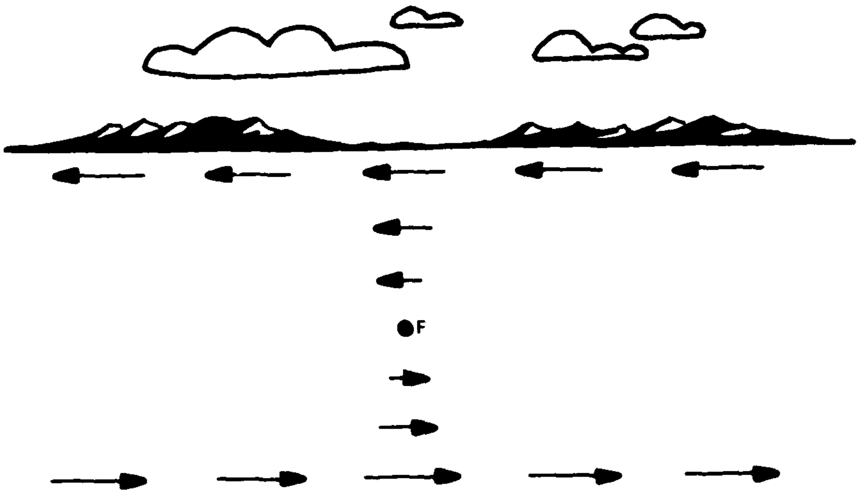
2.3 DISCUSSION

Given the lack of enriched environmental cues while transiting the waters available to accommodate large VLCCs, it is not surprising to find that by providing more points of reference a pilot can improve his maneuvering

performance while negotiating a channel bend. Typically as a terrestrial animal, the human is continuously in locomotion and subsequently is provided with many points of reference in space and time during is everyday activities. The visual system, therefore, has evolved in such a way as to make direct use of the diverse stimulus information which makes up our environment. Given our ecological nitche, which we occupy, our visual systems have evolved such that we can make the best use of information available in our environment (Gibson, 1979). Consequently, much of the processing of information in our environment is direct, that is, information is picked up directly by the visual system and carries specific meaning. Intermediate processing of such visual information is unnecessary and has been bypassed through evolution such that our species can adapt rapidly to its environment. However, when the human is transplanted from his nitche to either air or sea many of the stimulus arrays which we normally deal with directly are non-existent or have been altered in perspective. The key to providing the necessary information in these different air and sea environments is to determine what man typically picks up in terms of information in his terrestrial environment. Gibson (1979) has shown that these are characteristics, fundamental kinds of stimulus arrays or layouts which we typically respond to. For example, texture provides information about depth; the expansion of objects in space and time provide us with information concerning motion relative to an object. Differences in the apparent velocities of stationary objects as we move in space also give us information about direction of motion, Figure 7.

As a result, by placing more stationary reference points in an otherwise barren environment one can provide the pilot of a vessel with the necessary visual information resulting in the creation of a velocity gradient of motion. This gradient carries all of the information needed to determine direction of motion as well as position in space and time. Indeed the results of this study demonstrate how basic perceptual principles can be applied to improve ship control of a seemingly difficult to maneuver vessel such as a VLCC with an enormous mass. Nevertheless, the proper layout of stimuli in the environment (i.e., that which afford the human with information to which the visual system has evolved to pick up) can produce significant effects in altering shiphandling performance of a VLCC. It has also been shown that too much information in the case of the 1/8 nm spacing of buoys at the turn can produce the perception of a rigid barrier or obstacle which is to be avoided.

In conclusion, the results of this experiment point to the benefits of applying simple perceptual principles to provide the pilot with information which he customarily picks up while moving on land with its rich environmental stimulation. It was also shown that too little (1¼ nm spacing) or too much (1.8 nm spacing) produces less than optimal steering performance through the channel bend employed in this experiment. On the other hand, the data also speaks to the benefits of the Rate of Turn Indicator (ROTI) in compensating for the lack of information which was characterized by the low density buoyed turn scenario. In general, the results indicate that the medium density buoyed turn (i.e., ½ nm) affords the best information concerning direction of motion and position in space with the ROTI a close second. The ROTI is, however, better than no ROTI given present channel markings within the USA which are typically ¾ nm to 1¼ nm spacing.



The optical flow in motion parallax. Assume that an observer moving toward the left fixates a point at F. Objects nearer than F will appear to move in a direction opposite to that of the movement of the observer: objects farther away than F will appear to move in the same direction as the observer. The length of the arrows signifies that the apparent velocity of the optical flow is directly related to the distance of the objects from the fixation point. (From Gibson 1950.)

Figure 7. The Optical Flow in Motion Parallax

CHAPTER 3

EXPERIMENT 2

To further clarify the contribution of aids to navigation to steering through a turn, research was conducted at CAORF to examine the stimulus array necessary to optimize turning during night operations. Using the medium density buoy configuration, patterns of flashing were varied.

3.1 METHOD

Subjects: Six pilots with unlimited tonnage endorsements were selected to take part in the experiment. All pilots were members of the Sandy Hook Pilotage Association, New York, New York, USA. None of the pilots had experience maneuvering a vessel of the size employed in this experiment but have had experience on a variety of vessels of lesser size. All subjects had already participated in Experiment 1.

Scenario Design: The medium buoy density scenario from Experiment 1 was used. However, the environmental cues were changed to reflect nighttime conditions.

Vessel Characteristics: A 280,000 DWT VLCC was employed as the test vessel. Its characteristics were identical to that of Experiment 1.

Experimental Design: A within subjects analysis of variance design was used. The three conditions were:

Condition B_1 – Patterned flashing buoys. In this condition, all five buoy lights were on simultaneously for one second and then off for four seconds. On for one second, off for four seconds, etc.

Condition B_2 – Random flashing buoys in this condition, at least one buoy light was on at any one second period. However, the timing of their flashes was random.

Condition B_3 – Sequential flashing buoys. In this condition, Buoy 1 was on for one second. As Buoy 1 went off, Buoy 2 went on. As Buoy 2 went off, Buoy 3 went on, etc. Since five buoys were employed, the time interval between the onset of Buoy 1's first flash and its second flash was five seconds.

Experimental Procedure: Upon completion of Experiment 1, subjects were returned to CAORF to participate in Experiment 2. Since familiarization had already taken place prior to the first experiment, it was unnecessary for the second one. Each subject was required to transit the specified channel under each of the three flashing conditions. No radar, gyro, or rate of turn indicator was available. A uniform under keel clearance of 10 feet, a light and variable wind of 10 kts, and a variable but negligible current was present.

Performance Measures: The following measures of performance were recorded and used in the analysis of data:

1. Frequency of hard over rudder commands in direction of turn inferred to indicate the pilot's capability to negotiate a smooth, consistent turn.

2. Average track deviation reflecting the mean deviation from the center line of the channel while negotiating the turn.

3. Standard deviation of the track deviation reflecting the variability in trackkeeping about the center line.

4. Maximum deviation from track while maneuvering the channel bend.

5. Variability in rate of turn while maneuvering through the channel bend.

6. Swept path of vessel reflecting the area of the channel which the vessel occupies while steering through the turn. The closer swept path to the beam of the vessel, the greater the control over maintaining a steady turn.

3.2 RESULTS

The means and standard deviations of the performance measures for each flashing condition are presented in Table 3. Three significant differences in trackkeeping were found.

TABLE 3. MATRIX OF EXPERIMENTAL CONDITIONS BY PERFORMANCE MEASURES*

	B_1 Patterned Flashing	B_2 Random Flashing	B_3 Sequential Flashing
Total Frequency of Hard Over Rudder Commands	52 3.2	60 4.4	58 3.8
Average Track Deviation	71.26 46.13	97.72 61.34	98.80 63.42
Variability of Track Deviation	37.39 24.20	43.94 24.20	50.56 30.20
Maximum Track Deviation	131.58 79.38	161.55 77.90	164.52 92.97
Variability of Rate of Turn	0.063° 0.0179	0.066° 0.0196	0.067° 0.0108
Swepth Path	245.40 21.88	246.51 14.94	242.11 25.32

*Top values are means, bottom values are standard deviations of performance measures.

As Table 3 shows, the average track deviation for patterned flashing was 71.26; for random flashing, 97.72; and for sequential flashing, 98.80. The differences between patterned and random is statistically significant at the $p < 0.025$ level for a one-tailed t test. The casual observer may question why the difference between patterned and sequential is also not statistically significant. The low t value ($t = 1.30$) obtained when comparing B_1 to B_3 is an artifact of the variance associated with each condition. The standard deviation (which is the square root of variance) of the sequential condition is larger than that of the random condition. As variance increases about the means of conditions, the probability of finding significant differences between these means decreases. It is noteworthy that the patterned flashing condition yields the lowest variability in trackkeeping (SD = 46.13) relative to the other conditions. The highly variable trackkeeping of the sequential flashing condition relative to the other two conditions can also be seen by inspecting scores on the *performance measure* referred to in Table 3 as "variability of track deviation." Each subject's variability score was calculated by squaring his deviations from center line, summing these values, dividing by the total number of values, and then taking the square root of the product. Thus, each subject was given a standard deviation score reflecting his excursions away from center line. Dependent t tests performed on this measure reflect significant differences between the patterned ($\bar{x} = 37.89$) and sequential flashing conditions ($t = 1.52$, $p < 10$).

The patterned and random flashing conditions differed significantly in terms of maximum deviation ($t = 2.12$, $p < 0.05$). The mean maximum deviation for the patterned condition was 131.58 (SD = 38); for the random condition, 161.55 (SD = 77.90); and for the sequential condition, 164.52 (SD = 92.97). Once again, the standard deviation of the sequential flashing condition was large enough to preclude this condition from differing significantly from the other two conditions.

3.3 DISCUSSION

The better trackkeeping afforded by the patterned condition can be easily understood in terms of perceptual reference points. When the patterned buoys flashed on, they provided an unchanging configuration which the pilot could use as a reference point for steering. The random flashing condition, on the other hand, provided no constancy and, therefore, was used inconsistently by the pilots as a steering reference.

While the sequential flashing condition did not differ significantly from either of the other two conditions, an inspection of the means and standard deviations in Table 3 reveals that the sequential configuration yielded the most variable performance among pilots. This phenomenon may be due to the sequencing of flashes interacting with the pilot's perceived velocity gradient. To understand this explanation, the reader should refer to Figure 2. Figure 2 depicts the perspective of a pilot moving through a marked turn. The buoy closest to the pilot appears to move to the left most rapidly, while the buoy farthest from the pilot appears to move most slowly. The perceived speed to the distance travelled is used by the pilot as a perceptual cue for steering. However, if he sees only one buoy at a time in sequential order, the velocity gradient which he is accustomed to using as a cue is no longer afforded by the environment. He may respond by either using the existing cues improperly, adjusting his perception to these new cues, or disregarding the cues altogether. This confusion of responses may be responsible for the inconsistent performance among the pilots in the sequential flashing condition. The directionality of the sequenced flashes may also differntially affect trackkeeping. In light of this hypothesis, it would be interesting to compare the stern to bow directionality of the sequenced flashes used in Experiment 2 with a bow-to-stern condition.

Future research should investigate the interaction of buoy density anf flashing conditions. Although trackkeeping appears most accurate using patterned flashes on medium density buoys, these patterned flashes, when applied to high density buoys, may actually accentuate the rigid barrier effect of high density buoys reported in Experiment 1 and, thereby, reduce the accuracy of trackkeeping. Further experimentation will elucidate this issue.

3.4 PERFORMANCE COMPARISON IN EXPERIMENT 2 (DAY) TO EXPERIMENT 3 (NIGHT)

Although Experiment 2 as not originally designed for direct comparison with Experiment 1, certain conditions lend themselves to such comparison. Specifically, the medium density condition of Experiment 1, which was run with daytime features, could be compared to each of the three medium density flashing conditions of Experiment 2, which was run with nighttime features. This series of post hoc comparisons provides information about nighttime navigational performance relative to daytime performance employing the buoy density empirically found to be optimal for daytime use.

When day and night conditions were compared using frequency of hard over commands as the dependent measure, the daytime medium density condition (A_3) was found to differ significantly from the patterned (B_1), random (B_2), and sequential (B_3) flashing conditions. The means and statistics for these conditions were:

- Day vs. Patterned Flash Night (26 vs. 52), $t = 2.08$, $p < 0.05$.

- Day vs. Random Flash Night (26 vs. 60), $t = 2.25$, $p < 0.05$.

- Day vs. Sequential Flash Night (26 vs. 58), $t = 214$, $p < 0.05$.

One can infer from the fewer hard over commands used in the daytime condition that the pilot exercises control of the vessel with less rudder during the day compared to the night. We also know, from Experiment 2, that the types of flashes used at night do not influence the amount of hard rudder used.

Although average and maximum track deviation did not change from day to night conditions, the variability of trackkeeping increased under the random and sequential flashing conditions. The comparisons of track variability yielded the following results:

- Day vs. Patterned Flash Night (29.57 vs. 37.89), no significant difference.

- Day vs. Random Flash Night (29.57 vs. 43.94), $t = 1.75$, $p < 0.10$.

- Day vs. Sequential Flash Night (29.57 vs. 50.56), $t = 1.75$, $p < 0.10$.

The patterned flash condition appears to provide a stimulus array sufficient for the pilot to maintain the consistency of his trackkeeping at a level comparable to daytime performance. However, the random and sequential flashes do not afford consistent trackkeeping, perhaps because these conditions deprive the pilot of the environmental cues necessary to establish a velocity gradient from which he can steer.

Another measure of vessel control, swept path, also increased under night conditions relative to day:

- Day vs. Patterned Flash Night (230.45 vs. 245.40), $t = 2.03$, $p < 0.05$.

- Day vs. Random Flash Night (230.45 vs. 246.51), $t = 2.05$, $p < 0.05$.

- Day vs. Sequential Flash Night (230.45 vs. 242.11), $t = 1.72$, $p < 0.10$.

The larger crab angle associated with all the flashing conditions implies that pilots have less vessel control when negotiating a turn at night than during the day. Furthermore, we know from Experiment 2 that various nighttime flashing configurations do not substantially charge the resultant swept path.

In reviewing the comparison of Experiments 2 and 3, the reader must bear in mind that the results reported represent differences between day and night conditions for medium density buoys only. No nighttime high or low density conditions were run. Whether patterned, random, and sequential flashing patterns interact with buoy density can only be determined through further experimentation.

CHAPTER 4

CONCLUSIONS

The first experiment reviewed in this report was designed to examine the effect of buoy density and a rate of turn indicator on steering through a channel bend during daytime conditions. The data indicated that the medium density condition provided the optimal stimulus array for negotiating a turn. The low density condition did not offer the pilot sufficient reference points for him to establish a velocity gradient by which to steer. However, the addition of a rate of turn indicator to the low density condition changed the frequency of hard over rudder commands, the variability of rate of turn, and the swept path of the test vessel in a direction closer to the optimal medium density condition. The high buoy density condition appeared to offer more than the optimum amount of information necessary for steering. The track deviations and plots of the high density condition relative to the other condition indicated that the pilot perceives the high density configuration as a rigid barrier to be avoided and, thus, moves off center line in a direction opposite the buoy.

The second experiment tested the effects of various flashing conditions imposed upon medium density buoys at night. Results showed that the patterned flashes provide a constancy to the environment which aids the pilot in negotiating a turn smoothly with variability in trackkeeping no larger than during the day. The sequential flashing condition, on the other hand, stimulated the most variability in trackkeeping.

A comparison of the data from the first and second experiments indicated that trackkeeping at night can be maintained at the daytime level using patterned flashes. However, no nighttime flashing conditions could provide the vessel control, as measured by number of hard over commands and swept path, afforded by medium density buoys seen during the day.

Future research should examine the interaction of buoy density and flashing patterns as well as the contribution of directionality to sequentially flashing buoys.

CHAPTER 5

EPILOGUE

The two experiments reviewed in this report have focused entirely on the behavior of pilots during a turning maneuver. While the pilot's decisions are largely responsible for the successful execution of a turn, the helmsman's role must not be discounted. The helmsman is responsible for properly executing the pilot's orders as well as steadying up the vessel after a turn has been negotiated. Therefore, a program of research into "the human factor in steering" must also include a systematic investigatin of the helmsman's steering behavior. A second report entitled "Helmsman Performance on Ships During Turning Maneuvers" focuses on this issue.

REFERENCES

Gibson, J. S. **The Perception of the Visual World.** Boston, Houghton Mifflin, 1950.

Gibson, J. J. **The Ecological Approach to Visual Perception.** Boston, Houghton Mifflin, 1979.

Graham, C. H. Perception of Movement. In C. H. Graham (Ed). **Vision and Visual Perception.** New York: Wiley, 1965.

Kirk, R. E. **Experimental Design: Procedures for the Behavioral Sciences.** Belmont, California: Wadsworth Publishing Company, Inc., 1969.

Williams, K. E. and Gilder, M. **Perceptual Sensitivity of Masters and Pilots to Bearing, Yaw Velocity, and Change of Rate of Yaw as a Function of Ship Size.** Maritime Administration, Department of Commerce, USA. National Maritime Research Center/CAORF, Kings Point, New York, 1979 in press.

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